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MAGNETIC FIELD FLUCTUATIONS IN THE MAGNETOSHEATH OBSERVED BY PIONEER 7 AND 8

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MAGNETIC FIELD FLUCTUATIONS

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A B S T R A C T

Fluctuations of the magnetic field at frequencies less than 0.05 Hz have been studied in the magnetosheath from data obtained by Pioneers 7 and 8. During the first two weeks of their flight, the probes were in similar trajectories along an approximally radial directions from the earth to $250R_E$ at an earth - sun - probe angle of 30°.

Magnetic fluctuations inside the magnetosheath are essentially transverse to the field vector and the most excited field component is perpendicular to the ecliptic plane. The entire spectrum is excited, the spectral power being proportional to $f^{-\alpha}$, where $1 < \alpha < 2$ with no emphasis on any particular frequency.

The magnetic energy associated with the fluctuations is found to exponentially decay with increasing distance transverse to the Sun-Earth line. These results suggest that the fluctuations represent an enhanced micro-structure produced by the amplification of small convected irregularities occurring at the bow shock, as proposed by McKenzie and Westphal.

1. - I N T R O D U C T I O N . -

In this paper the results obtained by the magnetic field experiments on the space probes Pioneers 7 and 8 are presented with the purpose of studying the field fluctuations inside the magnetosheath at frequencies below 0.05 Hz. Previous satellite exploration of the magnetosheath has been made over short time intervals and mainly in portions of the magnetosphere at geocentric distances less than $40R_E$.

A unique feature of Pioneers 7 and 8 (from now on indicated by P 7 and P 8, respectively) is that their trajectories were imbedded in the magnetosheath in such a way as to allow a long observation time as well as an extended study of the distance

variation of the magnetic field to and well beyond $40R_E$. In addition, the different times of flight of the two probes permit a comparison of results obtained in different parts of the solar cycle. The ULF band below 0.05 Hz considered in this paper includes the slowly variable portion of the field in the hydromagnetic regime.

The intensity of the average ambient field in the magnetosheath of several gammas leads to a value of about 0.2 Hz for the proton gyrofrequency, so that the expected contributions should mainly come from: (i) the irregularities produced or contained in the micro-and in the macro-structure of the field convected by the solar wind (ii) the more or less regular fluctuations produced at the magnetopause and/or at the bow shock, possibly correlated with the magnetic activity on the ground.

2.- THE EXPERIMENT -

The same basic instrumentation consisting of a monoaxial fluxgate sensor oriented in a meridian plane at an angle = 54° 45' with respect to the spin axis, was used on P 7 and P 8. The only difference is in the instrumental ranges which were a single range ± 64 γ on P 7 and a double range ± 32 γ and ± 96 γ on P 8. The sensitivities, corresponding to 8 bit digitization, were respectively ± 0.25 γ, ± 0.125 γ and ± 0.375 γ. In P 8 the extended range ± 96 γ was only used in the very first hours of the flight, when the spacecraft was still close to the Earth and the field was strong.

Three consecutive samplings spaced in time by 1/3 of the spin period, 1 second, then led to a set of three orthogonal

field components. In the period of interest, the spacecraft telemetry rate was at its maximum, 512 bps, and the average interval between consecutive vector measurements was about 1.5 sec. The actual time interval between the telemetered data points for each component is an integer multiple of the spin period, with several blanks present since their transmission is synchronized with the telemetry.

For the purpose of spectral analysis, linear averages of each field component and of field intensity have been used over time intervals of 10 and 30 seconds, during which 7 or 8 and 23 or 24 single measurements were made, respectively. The bandpass of the instrument was approximately 0 - 5 Hz so that aliasing of spectral fluctuations above 0.05 Hz occurs. Since the spectra observed by these and other experiments are all rapidly decreasing functions with increasing frequency, this aliasing will not introduce a serious distortion of the general spectral shape or power levels.

P 7 was launched on August 17th, 1966 and P 8 on December 13th, 1967. Projections of their trajectories on the ecliptic plane are shown in Fig. 1, as well as the trajectories of several other probes or satellites with magnetic instrumentation whose results are relevant.

The spectral analysis has been made on the first 10 days of the P 7 flight and the first 15 days of the P 8 flight. Since the velocity of P 8 was smaller than that of P 7 by a factor of about 1.5, almost the same geometric region has been explored. However, it should be noted that the different season of the flight (August and December) and the different level of solar activity (average

Wolf number between August 16 and 31, 1966: R = 59; between December 10 and 30, 1967: R = 134, respectively) may lead to differences of physical characteristics of the magnetosheath.

Actually, after the two spacecrafts entered the magnetosheath, significant differences are noticed when the trajectories are expressed in solar magnetospheric coordinates. As Fig. 2 shows, the P 8 spacecraft is alternatively above and below the plane of symmetry of the magnetospheric cavity defined by the plane containing the neutral sheet. The distance of the neutral sheet from the ecliptic plane is indicated by $Z_{neutral}$. In contrast, following the first few hours of flight, P 7 is systematically above the symmetry plane.

3. THE EXPERIMENTAL RESULTS -

3.1. - The Magnetospheric Boundary. -

It has been determined (Lazarus et al. 1967) that P 7 entered the magnetosheath around 1900 UT of August 18th; before this the spacecraft was travelling in a region located on or very near to the neutral sheet. Subsequently the field was fluctuating almost continuously, changing both in intensity and orientation, as is characteristic in the magnetosheath. Some influence of the neutral sheet was still noticed for a short while around 2200 UT.

The magnetospheric conditions were not as well defined for P 8 as for P 7. A section of P 8 data is shown in Fig.3. The influence of the neutral sheet was first detected around 0130UT December 14th. However an inversion of the field orientation was observed only during a small percentage of time. The neutral sheet was probably approached again early in the afternoon of the same day, although the variance was still quite small. The field was almost continuously changing, even when the variance was at a very low level. It is clear that the spacecraft entered the magnetosheath between 0130 and 0330 UT December 15th, at a distance of about 25 R_E from the X_{SE}-Z_{SE} plane.

The P 8 magnetospheric radius of 25 R_E, a little larger than that observed by P 7,20 R_E, is very near to its estimated average value (Fig.1).

3.2. - Quantitative studies of Fluctuations. -

Visual inspection of the magnetic field data plotted in the time domain was first conducted. A conspicuous feature was the almost total absence of quasi-sinusoidal oscillations of either components or magnitude of the magnetic field. This may well be due to the lack of sufficient time resolution of the data since the averages used extended over many ion cyclotrons periods. The magnitude of the field, although quite variable, when compared to interplanetary conditions, as well as enhanced by about a factor of 2-4, was more variable in direction. This feature became more noticeable as the spacecrafts moved far distant from the Earth. The variability of the field magnitude direction and the magnitude itself decreased in a moderately consistent fashion.

In the absence of well defined wave trains and in an effort to conduct a quantitative study of the magnetic field fluctuations,

the power spectra of the data has been systematically studied. This provides, in addition, a detailed inspection of the frequency domain characteristics of the data in a much more sensitive manner than permitted by inspection of the time domain data plots.

Spectral power densities, as estimated by means of the auto-correlation technique (Blackman and Tukey, 1958) over typically three-hours time intervals have been computed. 30 seconds averages of the SE field components and of the field intensity were used. Sixty power estimates were computed to allow a good frequency resolution (1/3600 Hz) and yet to maintain moderately tight statistical confidence limits. Instrumental characteristics, as given in section 2, lead to a precision for the 30 seconds average, of about 0.05 γ for P 7 and 0.025 γ for P 8. The corresponding noise levels in the power are then 0.15 and 0.04 γ^2/Hz. In several cases 10 seconds averages were used. Although now the precisions are respectively 0.09 and 0.05 γ, the noise levels are approximately unchanged.

One important point for the interpretation of the results is that the convective motion of magnetic irregularities past the spacecraft occurs with a velocity which is 5 to 10 times greater than the phase velocity for the propagation of waves. Thus, spatial variations are observed rather than explicit temporal variations and the computed spectra are essentially <u>wave-number</u> rather than <u>frequency</u> spectra. However, because of the unknown orientation of any wave normals, it is not possible to uniquely convert from one to the other.

Figs. 4 to 6 show several examples of spectra computed for the individual field components and the field intensity: figs. 4 and 5 refer to three hours periods immediately before and after

P 7 entered the magnetosheath; Fig. 6 shows a spectrum from P 8 for a time interval shortly following its penetration into the magnetosheath. It appears that before P 7 enters the magnetosheath the power level of the Y_{SE} and Z_{SE} components is slightly lower than that of the field intensity, while a strong similarity of shape and values of X_{SE} and F spectra is noticed. This means that the field oscillates essentially parallel to the X_{SE} axis, and hence the average magnetic field but with superimposed torsional or transversal contributions. Once the magnetosheath is penetrated, the power densities of the field components become remarkably higher, by up to a factor of 10. The corresponding increase of the spectral density of F is significantly lower, which indicates that the transversal or torsional character becomes predominant. This is especially true at higher frequencies.

The spectral density consistently decreases approximately as $f^{-\alpha}$, with χ ranging between 1 to 2. It is to be noticed that, although the spectral shape is computed for an observer on the spacecraft, in the case of a power law, the spectrum seen by an observer moving with the plasma velocity is not changed, the only difference being a scaling factor in power level (Siscoe , et al., 1967).

The details of the spectra appear quite irregular when individual plots are considered or when spectral densities for different components or at different times are compared. Similar to the results of previous experiments, several statistically significant peaks are found. However, the frequency corresponding to them is not the same at different times. Occasional coincidence of the spectra for limited frequency bands is noticed between two compon-

ents or one component and the field intensity : an example is exhibited in Fig.5 by the Y_{SE} and Z_{SE} components at $0.15 \leq f/f_N \leq 0.6$.

The field fluctuations observed by P 8 exhibit slightly different features. There is no prominent maximum of the spectral density corresponding to the magnetopause crossing. The power levels are a factor of 10 lower than those observed by P 7 inside the magnetosheath. The transverse character is still evident, in particular at higher frequencies. The spectra of the X_{SE} and Z_{SE} components shown in Fig. 6 are quite similar to each other in shape and numerical values. However the frequency dependence is remarkably different at frequencies below and above the approximate value of 0.005 Hz.

Several spectra have also been computed from both Pioneers using 10 second averages of the field, in which case the Nyquist frequency is f_N = 0.05 Hz. Examination of these spectra does not add very much to previous results, although extended over a frequency interval three times longer. The same conclusion has been reached looking at lower resolution spectra, which were computed over one-hour intervals. An attempt to look for some "regularity" over longer time intervals, also leading to a better frequency resolution, was made using 12 hours time intervals. Some results for the field intensity are shown in Fig. 7 where the spectra from P 8 for six time intervals are considered. Due to the higher frequency resolution more peaks are now present although at different frequencies with respect to the spectra of Figs. 4 to 6. Several strong peaks occur especially on December 18th and coincidence is seen, occasionally, between the peaks at different times. This is true, for example, for periods around 400 sec. on December 20 and 22,

Some coincidence over shorter periods of time is also evident in several cases.

The overall picture of the results from both Pioneers is that even though the power at certain frequencies are often enhanced, on the average the entire spectrum is uniformily enhanced relative to interplanetary levels and the magnetosheath oscillations are essentially transverse. Generally speaking, the spectral density P(f) is approximated by the simple relationship $P(f)=P_o f^{-\alpha}$ with α ranging between 1 to 2.

3.3. - Time and Distance Variation of the Power.

A significant variation of the power densities is found when the time or distance behaviour is taken into account. The method used to study this characteristic has been that of computing the integrated power W contained in 10 equal frequency bands (indicated by 1, 2 etc.) each one $\frac{1}{600}$ Hz wide and observing their variation along the trajectory of the spacecraft. Spectra over three hours time interval have been used. Only time intervals when continuous data were available have been considered. Several gaps are then present in the data; in the case of P 8, unfortunately, there was a long gap early after the magnetopause was crossed when technical difficulties on the spacecraft occurred and data was excessively noisy.

Several plots of the apparent time variation of the integrated power W of the field intensity are shown in Figs. 8 and 9 for the three frequency bands $f \leq \frac{1}{600}$ Hz, $\frac{1}{300} \leq f \leq \frac{1}{200}$ Hz and $\frac{1}{100} \leq f \leq \frac{7}{600}$ Hz respectively indicated by F1, F3 and F7. On the same axis as time, the Y_{SE} coordinate and the geocentric distances of the probes are also given. It is quite clear that in the case of P 7 the integrated

power of the field intensity is near to a maximum when the magnetosheath is entered, the only exception being the lowest band, for frequencies $\lesssim \frac{1}{600}$ Hz. The maximum near the magnetopause indicates that the most intense fluctuations are produced near the magnetospheric boundary. The exception, curve F1, is due to the tendency of the field intensity to slowly decrease at increasing distances inside the magnetosphere. Similar features are also found for the field components.

The level of the integrated power is a roughly linearly decreasing function of time in these semilogaritmic plots; the dotted lines represent the best fit for an exponential curve

$$(1) \qquad W = W_o e^{-(t-t_o)/\tau}$$

as obtained using the individual data points after the time, t_o, when the magnetospheric boundary was crossed.

In the case of P 8, an exponential decrease of the integrated powers is also evident. Comparing with the observations of P 7, stronger fluctuations are now superimposed on the average, slowly decreasing, level. On the other hand, no clear maximum appears in the integrated power in proximity to the magnetospheric boundary although, in the higher frequency bands, the average level of W before entering the magnetosheath is lower than the extrapolated value obtained from the best fit curves.

The values of τ, computed by (1), for the three curves F1, F3 and F7, are respectively given by τ= 1.9, 1.8 and 2.1 days^{-1} for P 7 and τ= 8.0, 6.9 and 7.6 days^{-1} for P 8.

It is to be noticed that the difference of the values of τ for the two Pioneers is partially due to the different velocities

of the two spacecraft. On the other hand, the higher level of the power at the time of crossing the magnetopause for P 7 contributes to the faster decay of power for this spacecraft.

Because of the different spacecraft velocities a description of the spectral power as a function of the position within the magnetosheath is essential. A best fit has been made by assuming a similar expression to (1):

$$(2) \qquad W = W_o e^{-(r-r_o)/\varrho}$$

where r is any spatial coordinate (geocentric distance, X_{SE} or Y_{SE} coordinate of the spacecraft), r_o is the value of r at the magnetospheric boundary and ϱ is a characteristic distance. Use of the above mentioned parameters does not lead to large differences in the relative values of ϱ in different frequency bands and for different field components. However a slightly smaller scattering of the individual values of ϱ occurs when the Y_{SE} spacecraft coordinate is used in (2). Table I shows the quantities W_o and ϱ for this particular choice, computed for the three components of the field and for its intensity.

The table shows that comparable values of ϱ are obtained from both spacecraft for the different field components, the only exception being those for the bands 1, 2 and 3 of the Y_{SE} component and the systematically lower values of the field intensity for P 7.

The transverse character of the fluctuations is evident, as well as a much higher power level of the Z_{SE} component than for the other field components.

The energy densities derived from the results of Table 1 are

substantially compatible with those of Mariner 4, approximately in the same frequency range (Siscoe et al., 1967) in the sense that extrapolation to lower distances in (2) using our values of W_{θ} and leads to a comparable value. The same is true for the results from Pioneer 6 (Ness et al. 1966).

3.4.- Correlation with Geomagnetic Activity.-

Possible correlations between the magnetic fluctuations in the magnetosheath and on the ground have also been studied.

Looking at the individual power spectra, an increased magnetic activity tends to correspond to a flatter power spectrum, i.e. to a relative increase of the power in the higher frequency bands.

As regards the integrated power, reference is made to Figs. 8 and 9 on the top of which the planetary magnetic activity K_p, as well as the occurrence of s.s.c. are plotted. Data from P 7 show a strong increase of W in all the bands around August 23 and 24, 1966, probably associated with the increased magnetic activity. Results from P 8 show a strong peak coincident with the K_p increase and the s.s.c. occurring on December 18, 1967.

Thus a positive correlation apparently exists between the integrated powers W and K_p. Fluctuations of W, with respect to their best fit exponential decreases, for the three components and for the field intensity have been separately correlated with the index K_p. Corresponding correlation coefficients are generally between 0.3 and 0.6 with an absolute maximum of 0.764. Search of a possible time shift between variations of W and K_p was not successful. Only in P 7 is there a slight trend of the correlation

TABLE I - Best fit with $W = W_o e^{-(Y_{SE} - Y_{SEO})/\rho}$

PIONEER 7

frequency band	X_{SE} component W_o	X_{SE} component ρ	Y_{SE} component W_o	Y_{SE} component ρ	Z_{SE} component W_o	Z_{SE} component ρ	field intensity W_o	field intensity ρ
1	9.82	45.2	2.48	238	65.5	23.5	9.12	18.5
2	.762	45.2	.357	96.2	2.10	33.9	.830	19.3
3	.323	49.7	.183	75.7	.816	34.6	.455	18.3
4	.191	44.8	.152	47.8	.415	36.4	.229	19.5
5	.114	47.8	.115	44.0	.259	36.0	.158	19.8
6	.076	48.1	.086	45.8	.143	42.7	.108	21.0
7	.066	42.7	.059	46.1	.120	37.5	.088	20.4
8	.048	44.5	.044	46.7	.099	36.5	.058	22.2
9	.035	51.5	.045	42.4	.072	38.8	.050	22.5
10	.037	44.8	.037	44.1	.069	39.4	.046	23.8

P I O N E E R 8

	X_{SE} component		Y_{SE} component		Z_{SE} component		field intensity	
frequency band	W_o	ρ	W_o	ρ	W_o	ρ	W_o	ρ
1	14.4	35.1	10.8	39.7	51.6	25.3	5.33	33.2
2	1.03	34.7	.802	39.7	2.13	29.8	.426	30.3
3	.351	38.0	.294	42.7	.611	36.9	.139	36.8
4	.215	38.0	.175	42.7	.389	33.5	.100	33.1
5	.156	34.7	.113	42.7	.209	37.4	.070	32.6
6	.079	45.5	.071	48.1	.165	32.7	.037	40.1
7	.065	41.5	.071	39.5	.123	32.7	.038	32.5
8	.053	42.0	.042	46.1	.070	40.5	.026	39.4
9	.051	38.1	.031	52.6	.070	35.6	.025	37.7
10	.047	39.2	.036	45.0	.061	38.0	.023	39.4

coefficients to be higher when integrated powers are taken with a delay of the order of a few hours.

4. - DISCUSSION. -

Theoretical understanding of the physical processes inside the magnetosheath is far from satisfactory. Thus far, several simple models have been proposed for the origin of the fluctuations. Hydromagnetic waves in the magnetosheath have been indicated as the intermediate means of energy transfer from the solar wind to the inner magnetosphere. Dessler and Walters (1964) propose a model of a wagging magnetosphere and tail, where the oscillations are excited by variations of the relative amount of the magnetic and the kinetic energy density in the solar wind, as well as of the orientation of the interplanetary magnetic field. Predictions of this model, although different for the cases of wave lengths much greater or much less than the magnetospheric radius, are for an increased power when the planetary K_p index increases and for a greater relative increase at higher frequencies.

The model of a viscous interaction between the solar wind and the magnetospheric gas proposed by Axford (1964) has the consequence that a current circulation takes place inside the magnetosphere. The momentum and energy transfer occurs by means of reflection and refraction of longitudinal waves on the boundary of the magnetosphere. Lerche (1966) and Parker (1967) have shown that the conditions typical of the magnetospheric boundary, namely the solar wind flow parallel to the field lines, imply a small-scale non-equilibrium, which would also contribute to the geomagnetic activity as well as to the formation of the geomagnetic

tail.

Eviatar and Wolf (1968) also studied the dynamical instabilities in the magnetopause. They have found a strong resonance of field fluctuations with the proton cyclotron frequency. The solar wind particles are very effectively scattered to penetrate deeply into the magnetosphere.

McKenzie and Westphal (1968) studied the interaction of sound waves with an oblique shock. They find a strong amplification of small perturbations impinging on the bow shock of the order of the square of the Mach number. Even higher amplifications can occur under critical incidence.

The results obtained in this paper and their relevance to the above hypothesis are now summarized.

Firstly, enhanced magnetic fluctuations were observed which permitted identification of the presence of the magnetosheath to distances of $X_{SE} \simeq -220\ R_E$, $Y_{SE} \simeq -110\ R_E$, or geocentric radial distances of 245 R_E.

Throughout the magnetosheath, the entire power spectrum is enhanced at frequencies between 0 and 0.05 Hz, with no emphasis for any particular frequencies. Only a limited amount of coincidence of peaks is found between spectra taken a few hours apart from each other. An almost permanent feature of the observed magnetic noise is the transverse or torsional character of the fluctuations. The most excited field component is perpendicular to the ecliptic plane and hence the solar wind direction. Field oscillations have been identified approximately perpendicular to the boundary itself.

The magnetic energy associated with the fluctuations of the field components shows, for all frequency bands, a regular exponential decay with increasing distance transverse to the Sun-

Earth line. Significant fluctuations, moderately correlated with the planetary magnetic activity, are superimposed on the exponen- ential behaviour, expecially for the data from P 8 in which case a quasi semidiurnal periodicity seems identifiable.

There are significant indications that the fluctiations are more intense in correspondence to the ideal location of the neutral sheet. Actually P 7 crossed the magnetopause very near to the neutral sheet, i.e. with the spacecraft immersed in the thin plasma sheet surrounding the neutral sheet itself. A clear maximum of power was then observed. In the case of P 8, the cross- ing occurred several earth radii south of the neutral sheet, i.e; outside of the plasma sheet. The magnetospheric boundary was then penetrated with no strong excitation.

A significant increase of oscillation power was observed a few hours later, just when the spacecraft was near the ideal neutral and plasma sheets. In addition, the almost semidiurnal variation of the power could be related to the two daily cross- ings of the plane of the neutral sheet.

The conclusion is that the energy associated with the field fluctuations is higher on the magnetospheric equator but decreases with increasing distance from the Sun-Earth line. The different combination of the two effects may explain the differences of the distance variation of W observed

Another interesting result is the higher level of energy density associated with the Z_{SE} field component. No theoretical prediction of this feature has been given. We point out that the Z_{SE} axis is parallel to the average orientation of the geomagnetic dipole, so that it could act as a preferential axis.

The most important question arising from this paper is the physical reason for the exponential decrease of the energy density. The possibility that we are observing waves which are excited near the magnetopause and propagating toward the spacecraft is not well supported. Heppner et al. (1967) have shown evidence that waves (although at a much higher frequency) produced on the bow shock, are strongly absorbed in the magnetosheath. On the other hand, since the propagation velocity of hydromagnetic waves, is several times smaller than the plasma velocity, their propagation as viewed from the earth cannot occur at an angle greater than 15° -20° with respect to the antisolar X_{SE} direction. This means that any wave observed along the trajectory could not be produced on the magnetopause, since the spacecraft velocity is inclined more than 30° with respect to X_{SE}. Thus, although excitation of simple modes of oscillation is expected near the magnetopause, or inside the magnetosheath, we are led to suppose that the main contribution to the observed magnetic fluctuations comes from excitation at the bow shock. The amplified microstructure of the magnetic field is then convected, approximately parallel to the magnetic tail, by the solar plasma flowing in the magnetosheath.

A decreasing level of the fluctuations is to be expected at increasing distances from the Sun-Earth line, as the bow shock becomes weaker and this is just what the experimental evidence shows.

Convection of microstructures has already been shown by Fairfield (1968) and Mariani and Ness (1969), in comparisons of simultaneous field observations from Explorers 33, 34 and 35 and Pioneers 7 and 8 . Thus we suggest

that the mechanism of McKenzie and Westphal (1968) is most relevant to an explanation of these observations of magnetosheath fluctuations and their spatial behavior. The significance of this interpretation for other measurements in the subsolar magneto-sheath should be investigated.

5. - ACKNOWLEDGEMENTS.-

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FIGURE CAPTIONS

Fig. 1 - Trajectories of several probes and satellites projected on the ecliptic plane. For the earth's satellites only some portions are indicated. For Explorers 33 and 35, only the portions simultaneous with the P 7 and P 8 data are plotted. For Explorer 34 and OGO-1 only the rotation of the apogee vector extreme is indicated. Dates on the Pioneers trajectories are for August 1966 and December 1967. The crosses on the Pioneers trajectories indicate the observed position of the magnetospheric boundary.

Fig. 2 - Projection of the trajectories of P 7 and P 8 on the solar magnetic (Z_{SM} X_{SM}) and solar ecliptic (Z_{SE} X_{SE}) meridian planes. Also shown are the distance of the ideal neutral sheet from the solar magnetospheric equatorial plane, according to the model by Speiser and Ness (1967). Dates are indicated on the Z_{SM} plots (The X_{SE} and X_{SM} are coincident by definition).

Fig. 3 - 30 sec averages of the variance D , the field intensity F, the inclination TH($=\vartheta_{SE}$) and the azimuth PHI($=\phi_{SE}$) during two selected time intervals for P 8. The variance D is the invariant of the coordinate system defined by

$$D = \left[D_x^2 + D_y^2 + D_z^2\right]^{\frac{1}{2}}$$

, where D_x , D_y , and D_z are the RMS deviations of the individual field components.

Fig. 4 - Power spectral densities of the SE field components X, Y, Z, and the intensity F observed by P 7 over the

three hours interval 1500 to 1800 August 18, 1966. The numerical values indicated on the power scale give spectral densities in γ^2/Hz once they are divided, for each plot, by the factor within parantheses. Uncertainties corresponding to 95% and 80% confidence level are shown. The Nyquist frequency f_N is 1/60 Hz. On the lower scale periods in seconds are also indicated.

Fig. 5 - Power spectral densities after magnetopause crossing by P 7, for the time interval 1900 to 2200 August 18, 1966. Same conventions as in Fig. 4.

Fig. 6 - Power spectral densities after magnetopause crossing by P 8, for the time interval 0500 to 0800 December 15, 1967. Same conventions as in Fig. 4.

Fig. 7 - Power spectral densities in the magnetosheath for several 12 hours intervals, observed by P 8 in 15 to 22 of December 1967. Best fit ($f^{-\alpha}$) curves are shown (dotted). The values of α are indicated on the right near each curve. Same conventions as in Fig. 4.

Fig. 8 - Three examples of time variation of the integrated power of the field intensity from P 7, over the three frequency bands 1, 3 and 7 respectively indicated by F1, F3 and F7. The integrated power is expressed in γ^2 after division of the values on the power scale by the factor indicated over each curve. On the top the planetary index K_p is also plotted. At the bottom the coordinate Y_{SE} and the geocentric distance at the beginning of each day are given in units of R_E. Dotted lines indicate best fit

interpolations of the data.

Fig. 9 - The same as in Fig. 8, from P 8 data.

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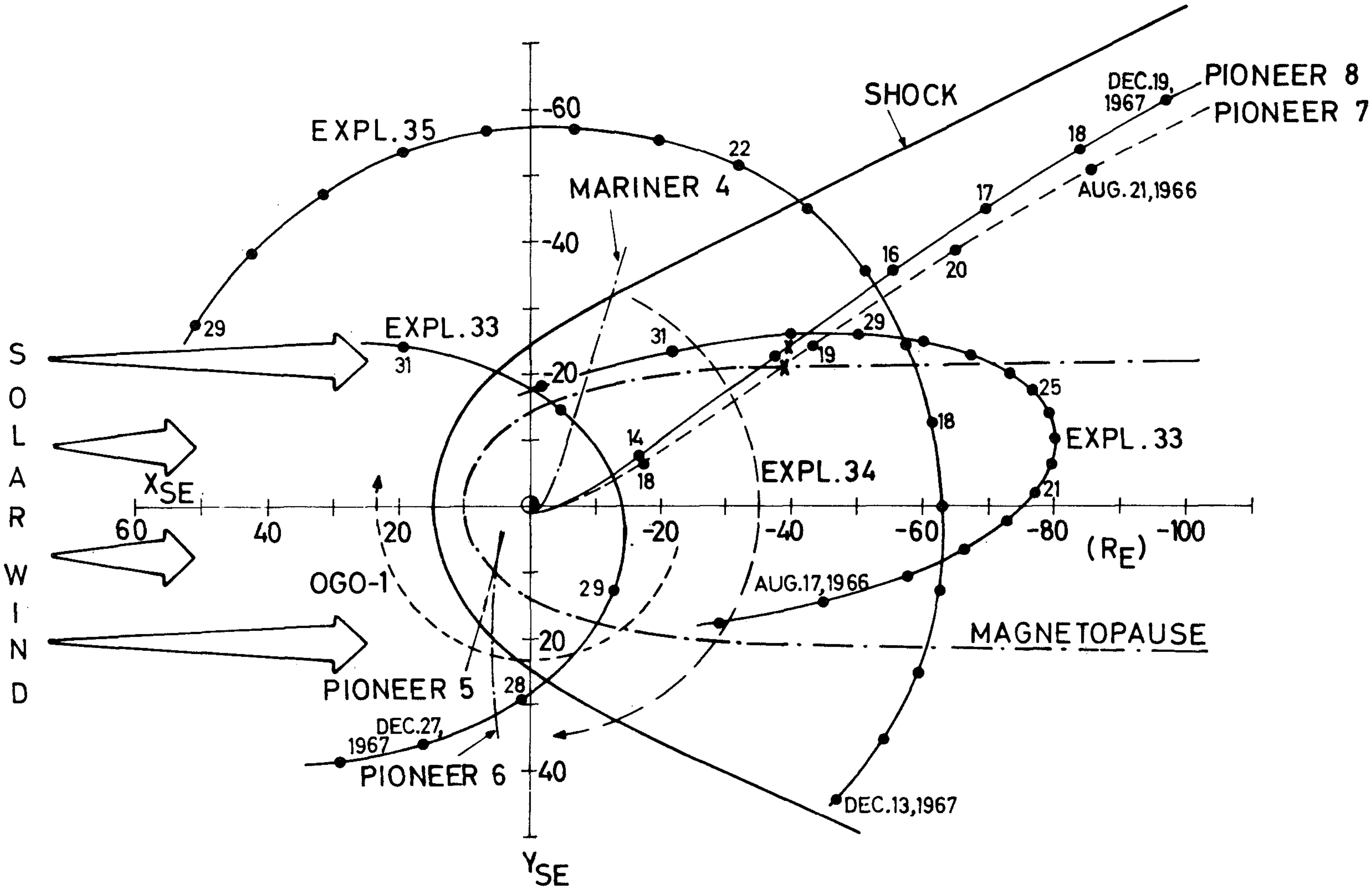
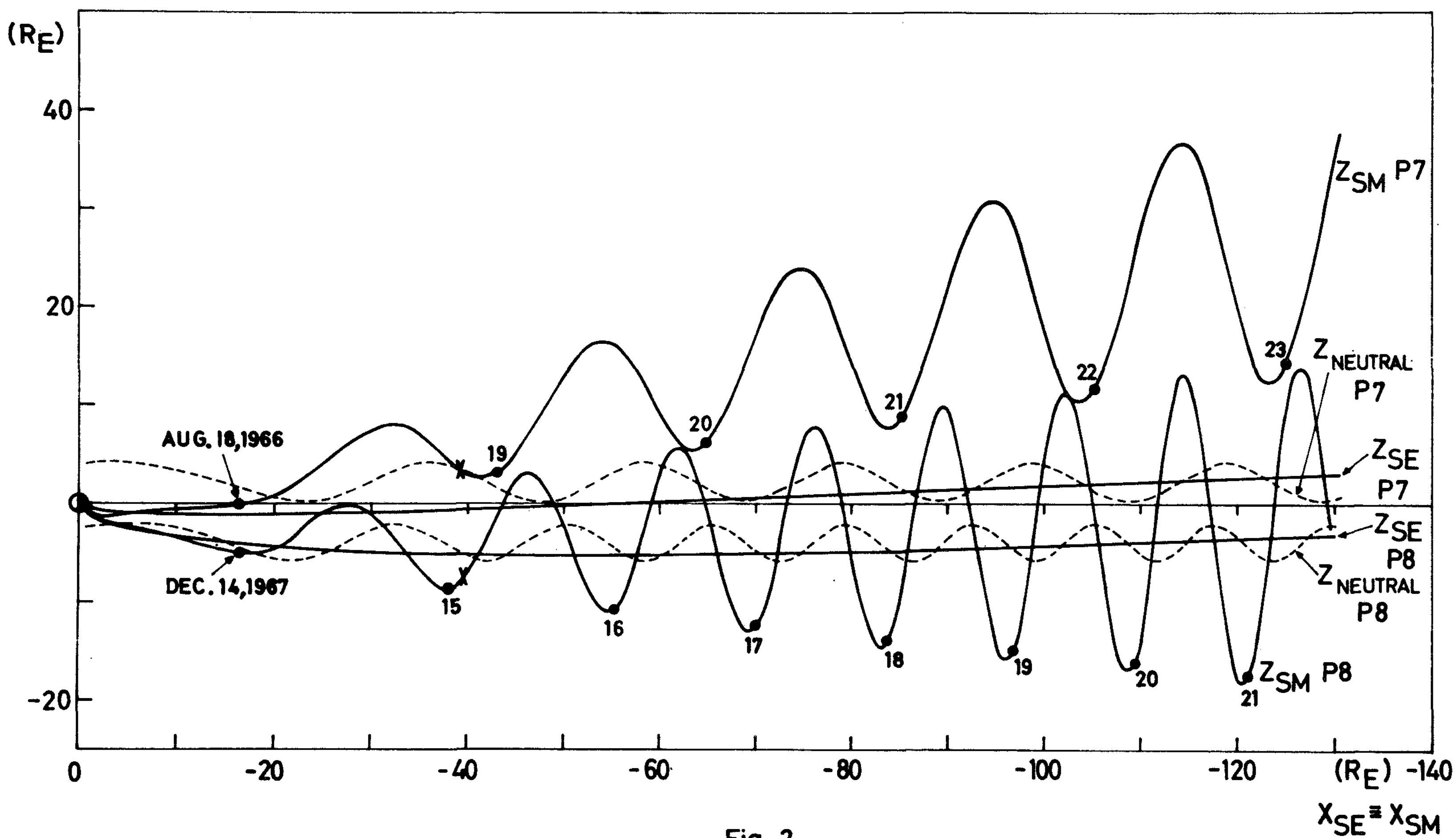
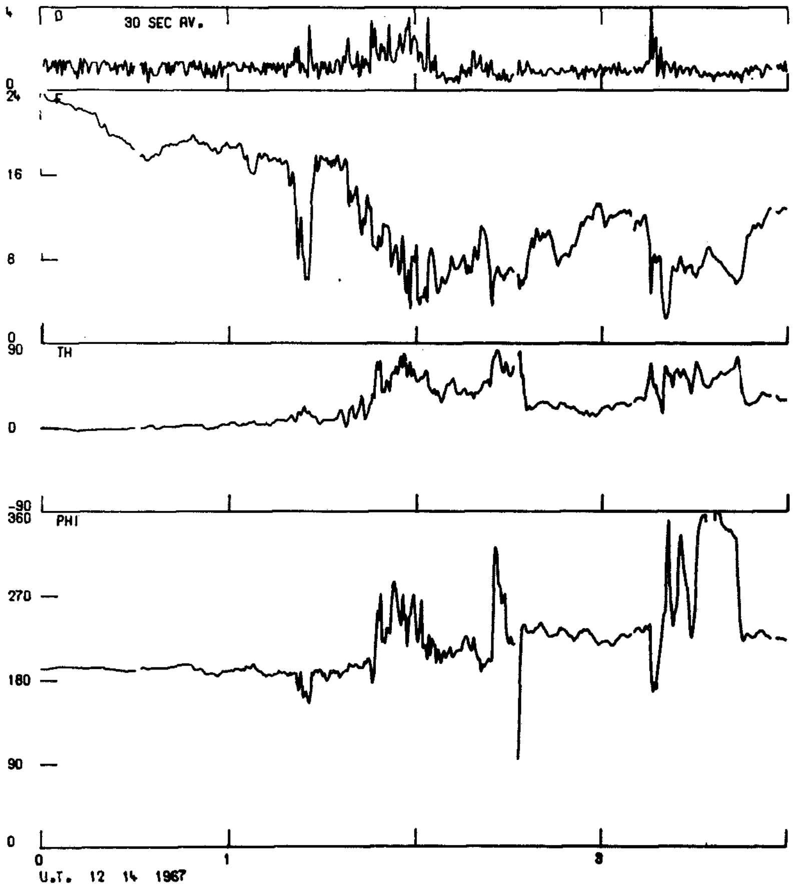

SOLAR WIND
SHOCK
PIONEER 8
PIONEER 7
DEC.19, 1967
AUG. 21, 1966
EXPL. 35
MARINER 4
EXPL. 33
EXPL. 34
OGO-1
PIONEER 5
PIONEER 6
DEC.27, 1967
AUG.17, 1966
DEC.13, 1967
MAGNETOPAUSE
X_{SE}
Y_{SE}
(R_E)
60
40
20
-20
-40
-60
-80
-100

Fig. 1

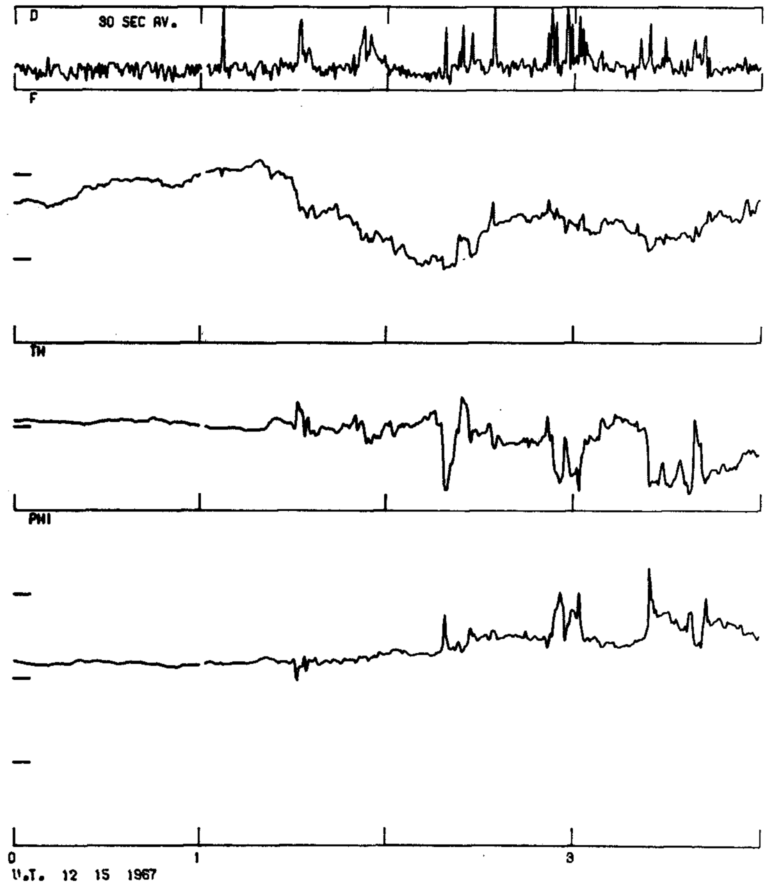


(RE)
40
20
-20
0
-20
-40
-60
-80
-100
-120
(RE) -140
XSE ≡ XSM
ZSM P7
ZNEUTRAL P7
ZSE P7
ZSE P8
ZNEUTRAL P8
ZSM P8
AUG. 18, 1966
DEC. 14, 1967
15
16
17
18
19
20
21
19
20
21
22
23

Fig. 2



4
D
30 SEC AV.
0
24
F
16
8
0
90
TH
0
-90
360
PHI
270
180
90
0
0
1
3
U.T. 12 14 1967



D
30 SEC AV.
F
TH
PHI
0
1
3
U.T. 12 15 1967

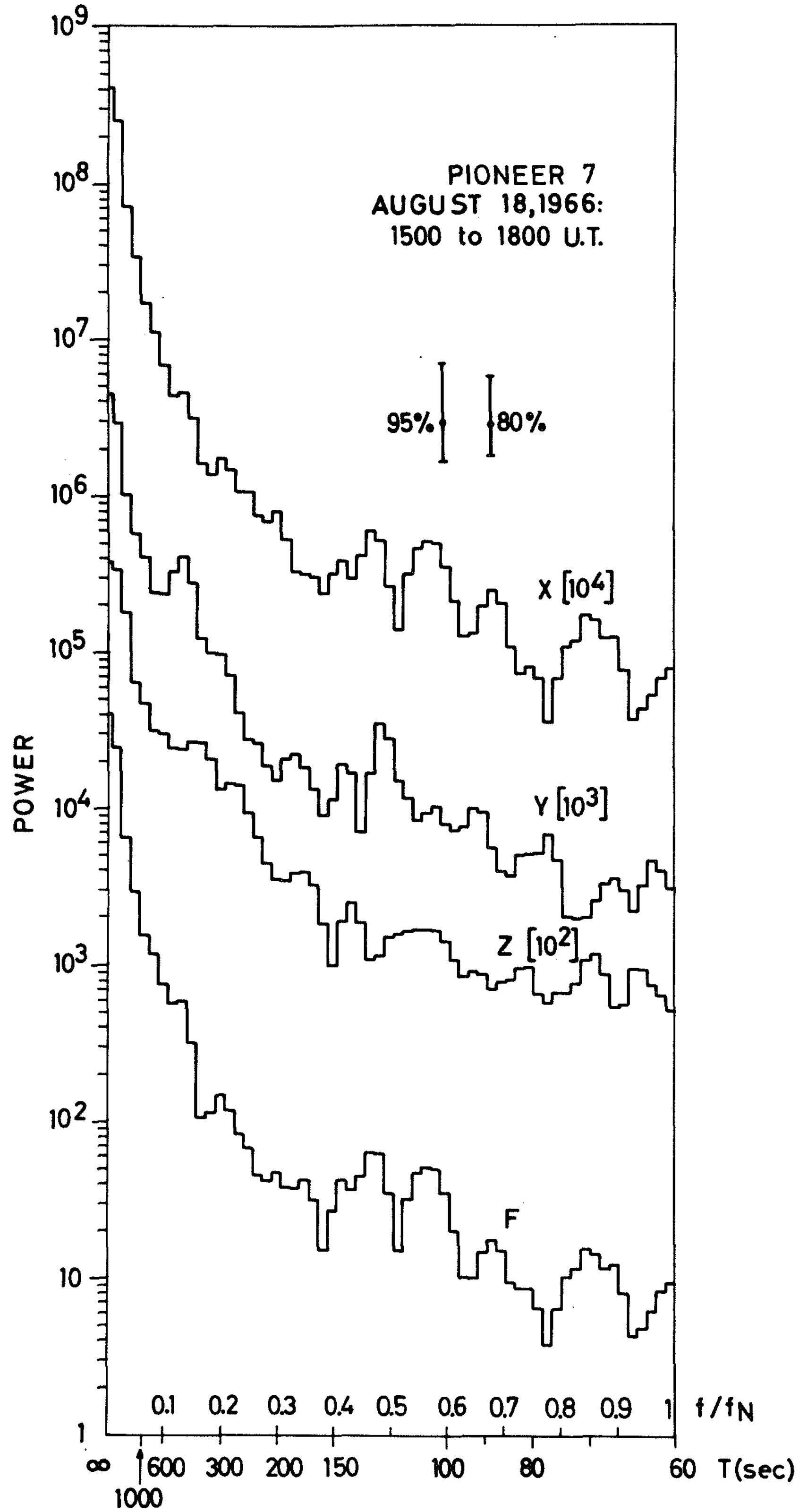

PIONEER 7
AUGUST 18,1966:
1500 to 1800 U.T.
95%
80%
POWER
X [10^4]
Y [10^3]
Z [10^2]
F
f/fN
T(sec)
1000

Fig. 4

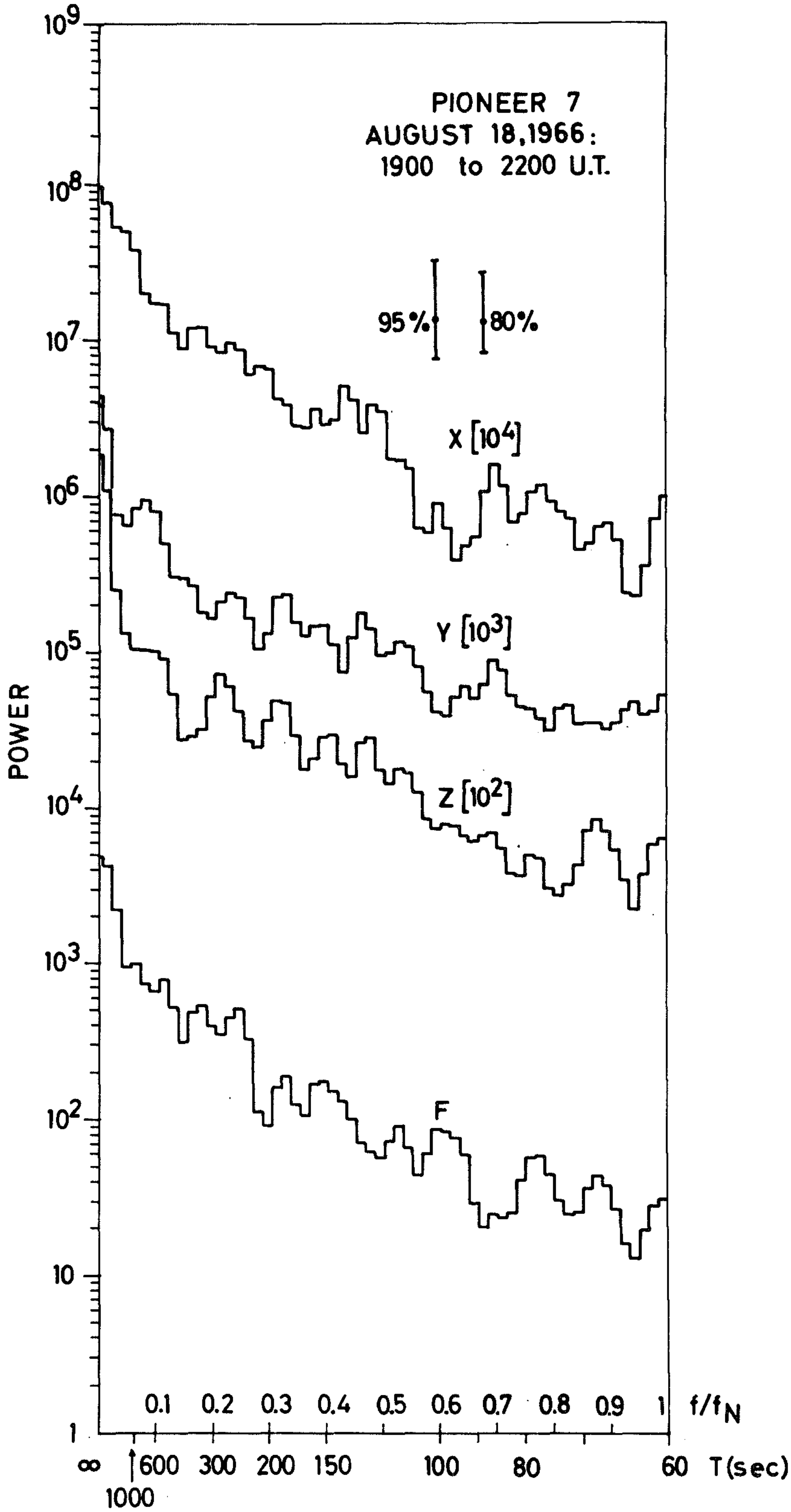
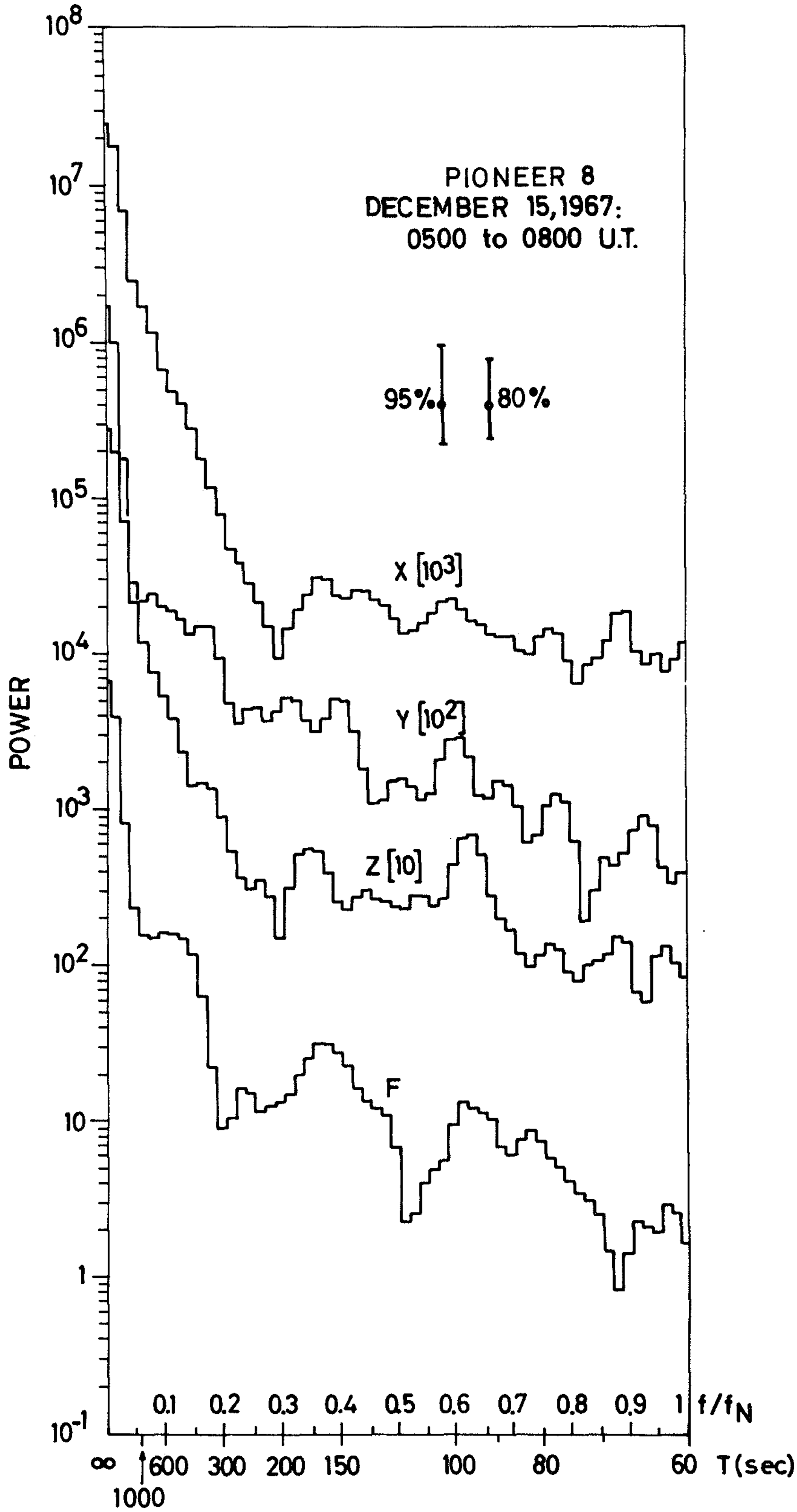

PIONEER 7
AUGUST 18,1966:
1900 to 2200 U.T.
95%
80%
X [10^4]
Y [10^3]
Z [10^2]
F
POWER
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10
1
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 f/f_N
∞ 1000 600 300 200 150 100 80 60 T(sec)

Fig. 5



PIONEER 8
DECEMBER 15,1967:
0500 to 0800 U.T.
95%
80%
X [10³]
Y [10²]
Z [10]
F
POWER
10⁸
10⁷
10⁶
10⁵
10⁴
10³
10²
10
1
10⁻¹
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 f/f_N
∞ 1000 600 300 200 150 100 80 60 T(sec)

Fig. 6

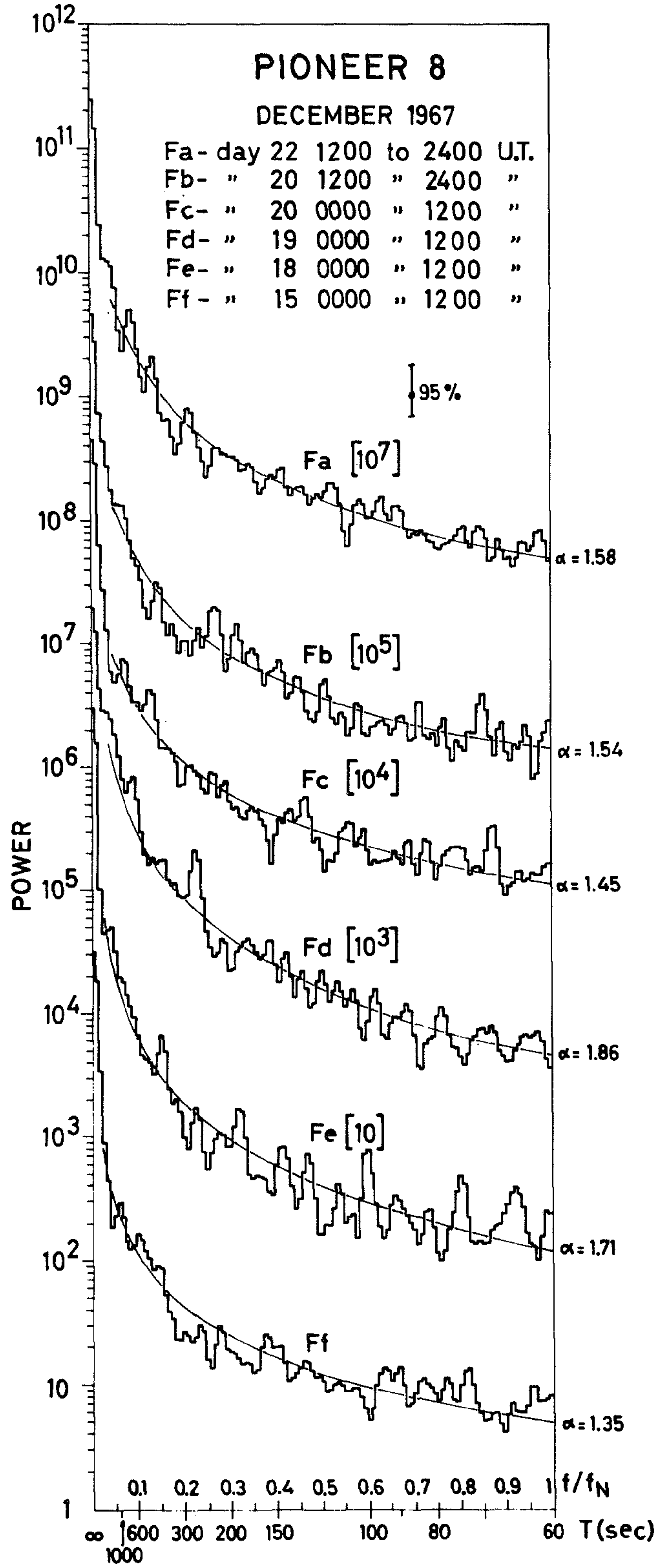
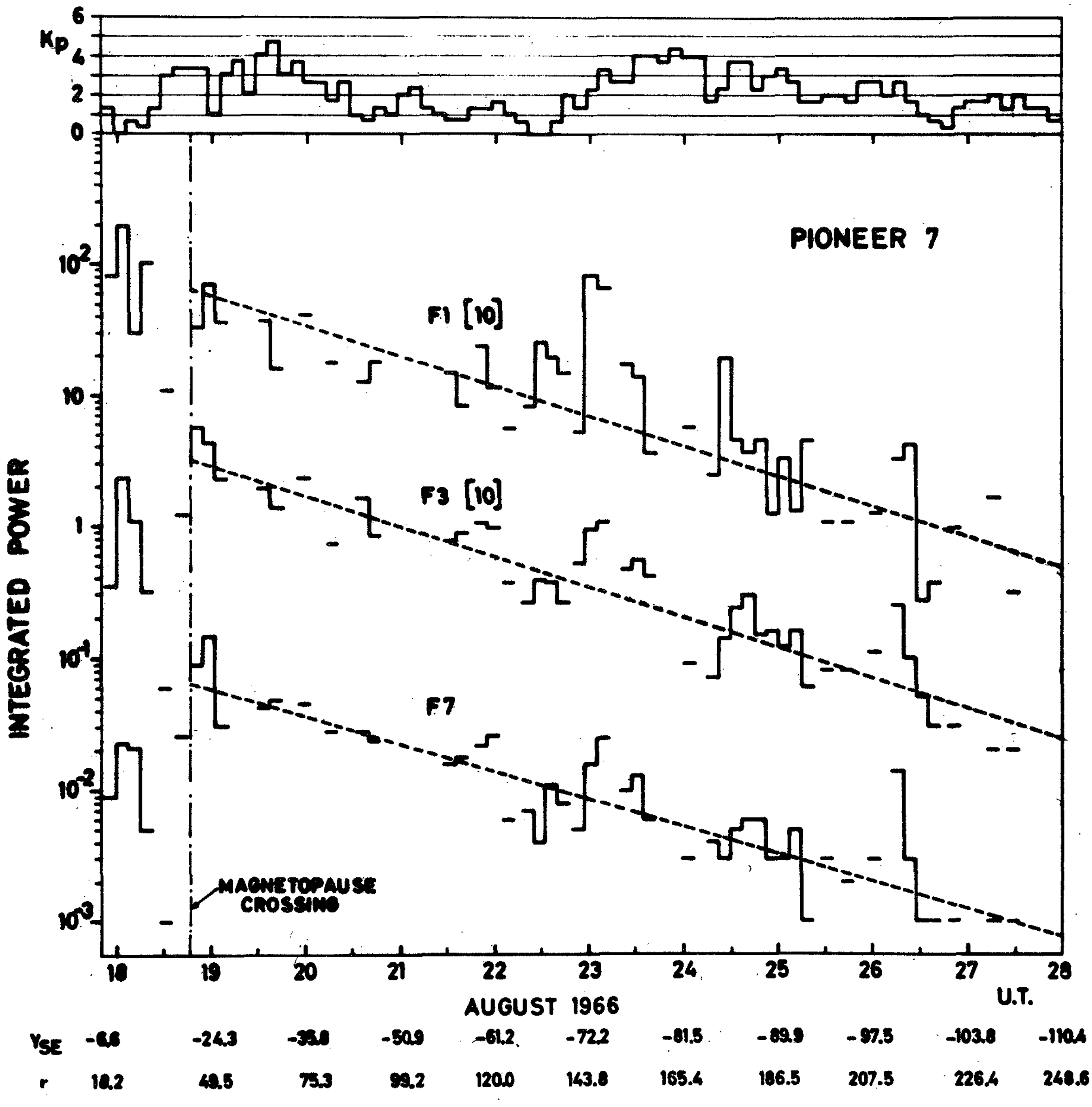
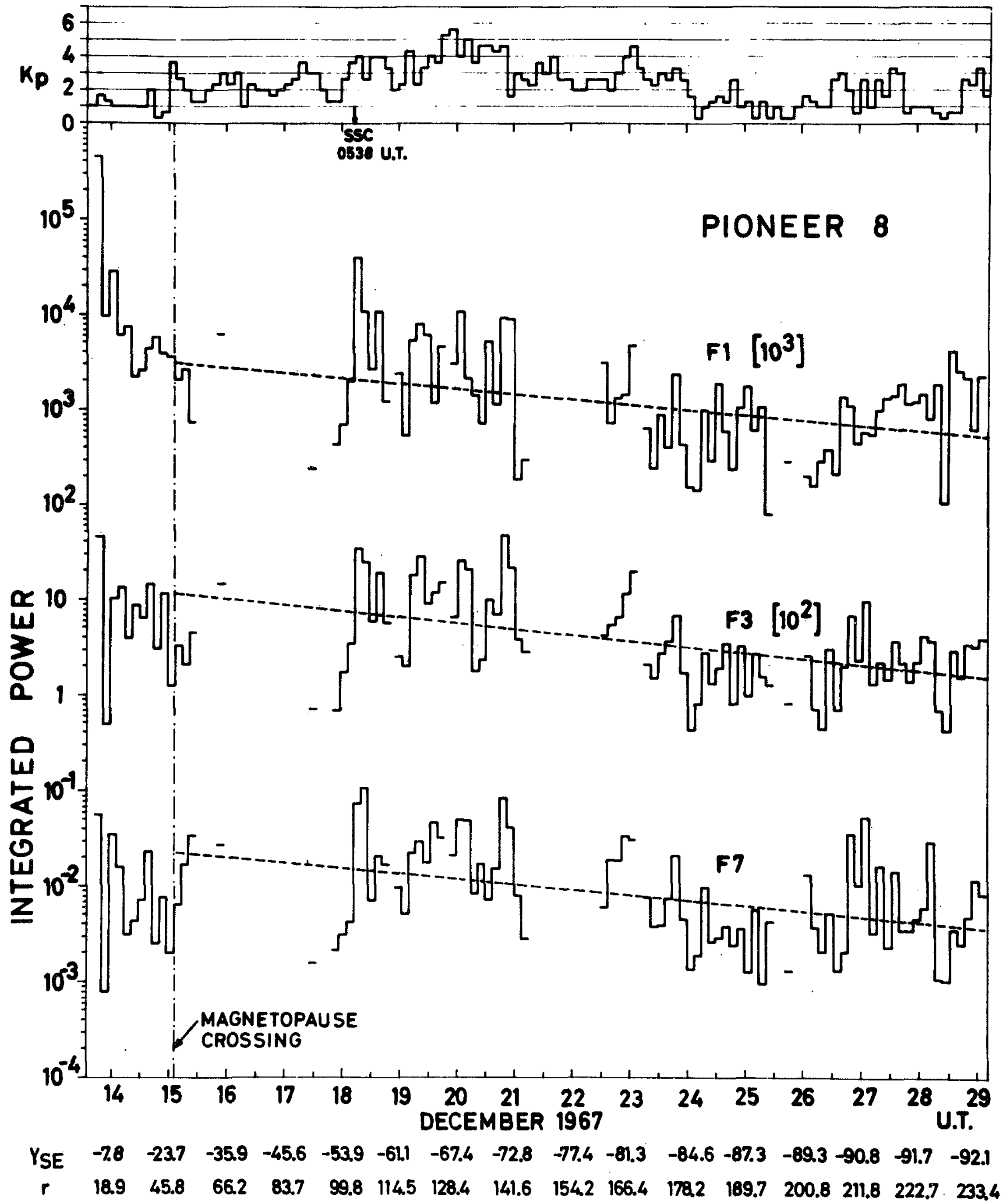

PIONEER 8
DECEMBER 1967
Fa - day 22 1200 to 2400 U.T.
Fb - " 20 1200 " 2400 "
Fc - " 20 0000 " 1200 "
Fd - " 19 0000 " 1200 "
Fe - " 18 0000 " 1200 "
Ff - " 15 0000 " 1200 "
95 %
Fa [10^7]
Fb [10^5]
Fc [10^4]
Fd [10^3]
Fe [10]
Ff
α = 1.58
α = 1.54
α = 1.45
α = 1.86
α = 1.71
α = 1.35
POWER
f/f_N
T (sec)

Fig.7



Kp
PIONEER 7
F1 [10]
F3 [10]
F7
INTEGRATED POWER
MAGNETOPAUSE CROSSING
AUGUST 1966
U.T.
18 19 20 21 22 23 24 25 26 27 28
Y_{SE} -6.6 -24.3 -38.8 -50.9 -61.2 -72.2 -81.5 -89.9 -97.5 -103.8 -110.4
r 18.2 48.5 75.3 98.2 120.0 143.8 165.4 186.5 207.5 226.4 248.6

FIG. 8



Kp
0
2
4
6
SSC
0538 U.T.
PIONEER 8
INTEGRATED POWER
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
F1 [10^3]
F3 [10^2]
F7
MAGNETOPAUSE CROSSING
14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
DECEMBER 1967
U.T.
Y_{SE} -7.8 -23.7 -35.9 -45.6 -53.9 -61.1 -67.4 -72.8 -77.4 -81.3 -84.6 -87.3 -89.3 -90.8 -91.7 -92.1
r 18.9 45.8 66.2 83.7 99.8 114.5 128.4 141.6 154.2 166.4 178.2 189.7 200.8 211.8 222.7 233.4

FIG. 9